

Impact flux of asteroids and water transport to the habitable zone in binary star systems

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Abstract. By now, observations of exoplanets have found more than 50 binary star systems hosting 71 planets. We expect these numbers to increase as more than 70% of the main sequence stars in the solar neighborhood are members of binary or multiple systems. The planetary motion in such systems depends strongly on both the parameters of the stellar system (stellar separation and eccentricity) and the architecture of the planetary system (number of planets and their orbital behaviour). In case a terrestrial planet moves in the so-called habitable zone (HZ) of its host star, the habitability of this planet depends on many parameters. A crucial factor is certainly the amount of water. We investigate in this work the transport of water from beyond the snow-line to the HZ in a binary star system and compare it to a single star system.

Keywords. Dynamics, celestial mechanics, binary star

Introduction

Water is the main ingredient defining a habitable planet. Therefore, the main question we would like to answer in our study is if a dry or almost dry planet can be fed with water by a bombardement of wet small bodies in binary systems. First simulations of planetary formation in such systems show the stochastic behaviour of the water to mass ratio of planetary embryos (Haghighipour and Raymond (2007)). After the planetary formation, a remnant disc of small bodies can be found around the main star. It mainly contains asteroids and comets whose initial water distribution depends on their relative position to the snow-line. In our study, we mainly tackle the question of the amount of water available in the HZ. To this purpose, we consider various binary star systems where both stars are G types. We analyse the dynamics of a ring containing 100 asteroids (with maximum mass equal to the mass of Ceres) initially placed beyond the snow-line (2.7 au for a primary G star) moving under the gravitational perturbation of the binary stars and a Jupiter at 5.2 au. The systems were studied numerically for 10 Myr. To make this study statistical, each disk is cloned 100 times. Thus the statistics is made with 10000 asteroids.

Results

Figure 1 (left panel) shows the statistics on the asteroids dynamics. The perturbations of both Jupiter and the binary companion will drastically influence the asteroids in the ring and may increase their eccentricities and evolve beyond their initial semi-major axis borders. This behaviour is highlighted by the increasing value of the probability for an asteroid to cross the HZ as a function of the periastris distance. They are called habitable zone crossers (HZc). As a consequence, the ring will be depopulated because the dynamics

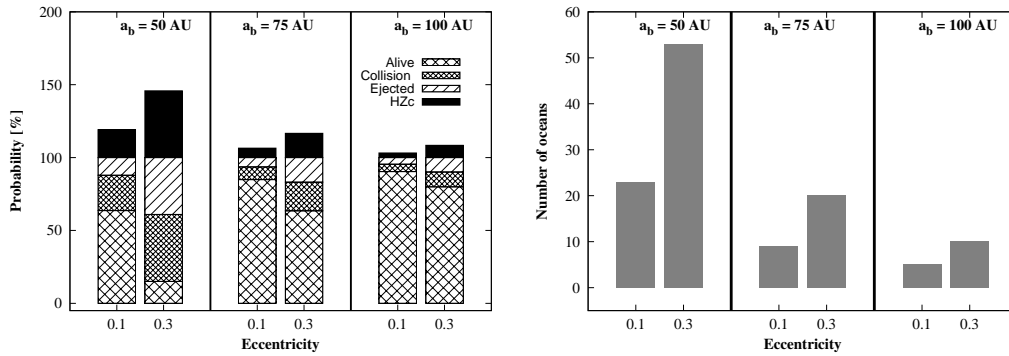


Figure 1. Left panel: Statistics on the asteroid’s dynamics as a function of the binary’s eccentricity and semi-major axis a_b . Each pattern refers to the probability for an asteroid initially in the ring to collide with the stars or Jupiter, be ejected or still be present in the system after 10 Myr. HZc refers to the probability for an asteroid to cross the HZ. Right panel: Quantity of water (in ocean units) transported to the HZ assuming also a water loss due to ice sublimation.

will induce ejections of asteroids and collisions with Jupiter and the stars. Therefore, the probability for an asteroid initially in the ring to stay in the system (“alive”) after 10 Myr will decrease with the periapsis distance of the secondary. Assuming an initial water content of 10% for each asteroid, we derived the water to mass fraction when it first enters the HZ. This corresponds to the maximum value of transported water by this asteroid. We also assume a water loss process due to ice sublimation caused by the radiation of both stars. Indeed, we estimated up to 14% contribution of the secondary star during the sublimation process. The right panel of Fig. 1 shows the total amount of water transported (in ocean units) by the HZc among the 10000 asteroids of all rings. As we can see, a binary companion on an eccentric orbit helps for a more efficient transport. Indeed, the ring is highly perturbed because the presence of Jupiter will induce secular perturbations. Only a few oceans can be transported for the most distant secondary stars because of the small flux of incoming asteroids in the HZ. This means that the timescale to drastically increase the transport of water must be beyond 10 Myr. This test shows how efficient a system can be to rapidly transport water to the HZ. However, we estimated that the maximum duration for the last HZc to bring water to the HZ is less than 0.25 Myr. This suggest a transport in more than one step as some systems still have more than 50% of asteroids in the ring (i.e. they have never crossed the HZ). Finally, we estimate that the water transport is ~ 4 – 5 less efficient if the system is not a binary.

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References

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